# EXPERIMENTAL AND NUMERICAL STUDY ON SHEET METAL LATERAL BENDING WITH BOTH ENDS FIXED

MOHD SHAHRIL BIN MOHD HASSAN

A report submitted in partial fulfillment of
The requirements for the award of the degree of
Bachelor of Mechanical Engineering with Manufacturing Engineering

BACHELOR OF ENGINEERING
UNIVERSITI MALAYSIA PAHANG

2012

## ABSTRACT

The main aim of this study is to compare the buckling phenomenon of sheet metal strip under both ends fixed setting. This study begins with a literature study. It was followed by design and fabrication of test equipment for strip buckling test. Initial research works was on design the test rig using solidwork software. The fabrication test rig consists of four different buckling test conditions. In this thesis, experimental and numerical investigation was dedicated to both ends fixed. Using the fabricated test rig, experimental was conducted to determine displacement and strain of the buckle specimen. Data from experiment have been compared with numerical modeling using Abaqus software. The results show good agreement between experimental and numerical analysis.

# ABSTRAK

Tujuan utama kajian ini adalah untuk membandingkan fenomena lengkokan jalur logam nipis dimana kedua-dua hujung adalah dalam keadaan yang tetap. Kajian ini bermula dengan rujukan awal dari bahan rujukan yang berkaitan. Seterusnya diikuti oleh reka bentuk dan pembuatan peralatan ujian bagi ujian jalur lengkokan. Kerja-kerja penyelidikan asal adalah pada reka bentuk pelantar ujian dengan menggunakan perisian solidwork. Pelantar ujian yang dihasilkan terdiri daripada empat keadaan berbeza ujian lengkokan. Dalam tesis ini, penyiasatan eksperimen berdedikasi pada satu keadaan iaitu kepada kedua-dua hujung yang ditetapkan. Menggunakan pelantar ujian yang dihasilkan, eksperimen telah dijalankan untuk menentukan perubahan panjang pada lengkukan dan jarak perubahan spesimen. Data dari eksperimen telah berbanding dengan model yang sama seperti eksperimen menggunakan perisian Abaqus. Hasil kajian menunjukkan perbubungan antara analisis eksperimen dan simulasi.

# TABLE OF CONTENTS

# LIST OF TABLE

# LIST OF FIGURES

# LIST OF ABBREVIATIONS

| | |
|---|---|
| FEM | Finite Element Method |
| FEA | Finite Element Analysis |
| PDE | Partial Differential Equations |
| 3D | 3 Dimensions |
| SMAW | Shielded Metal Arc Welding |
| CNC | Computer Numerical Control |
| WF | Wide-Flange |

# CHAPTER 1

# INTRODUCTION

## 1.1 Introduction

This chapter gives a short description of the project background including several approaches. It then introduces objectives, scopes, problem statement of this project on fabricate the laboratory test equipment for sheet metal lateral bending(buckling) condition where the both ends are fixed.

## 1.2 Project Background

This project focus on design new experimental for buckling test equipment, beside, run the experiment of strip buckling which both condition are fixed. It is also explain about concept and practically on buckling process and simulation by using finite element method (FEM).

### 1.2.1 Buckling Phenomena

Buckling is one of the natural phenomena in engineering field which is related to unstable structure of the object. Theoretically,buckling is a mathematical instability, leading to a failure mode and caused by a bifurcation in the solution to the equations of static equilibrium. At a certain stage under an increasing load or force, further load is able to be sustained in one of two states of equilibrium. In practice, buckling is characterized by a sudden failure of a structural subjected to high compressive stress, where the actual compressive stress at the point of failure is less than the ultimate compressive stresses that the material is capable of withstanding. Mathematical analysis of buckling makes use of an axial load eccentricity that introduces a moment, which does not form part of the primary forces to which the member is subjected. When load is constantly being applied on a member, such as strip, it will ultimately become large enough to cause the member to become unstable. Further load will cause significant and somewhat unpredictable deformations, possibly leading to complete loss of load carrying capacity and failure of structures stability.

### 1.2.2 Buckling of Strip

When a structure subjected to compression undergoes visibly large displacements transverse to the load then it is going to buckle. Buckling may be demonstrated by pressing the opposite edges of a flat sheet of cardboard towards one another. For small loads the process is elastic since buckling displacements disappear when the load is removed. Local buckling of plates or shells is indicated by the growth of bulges, waves or ripples, and is commonly encountered in the component plates of thin structural members. Buckling proceeds in manner which may be either:

(i) Stable: Condition in which case displacements increase in a controlled fashion as loads are increased. The structure's ability to sustain loads is maintained.

(ii) Unstable: Condition in which case deformations increase instantaneously, the load carrying capacity loses, thus it is dives and the structure collapses.

(iii) Neutral equilibrium: It is also a theoretical possibility during buckling and this is characterized by deformation increase without change in load.

Buckling and bending are similar in that they both involve bending moments. In bending, moments are substantially independent of the resulting deflections, meanwhile in buckling the moments and deflections are mutually inter dependent and also moments, deflections and stresses are not proportional to loads. If buckling deflections become too large then the structure fails, this is a geometric consideration, completely separate from any material strength consideration. If a component of part is prone to buckling then its design must full fill both strength and buckling safety constraints.

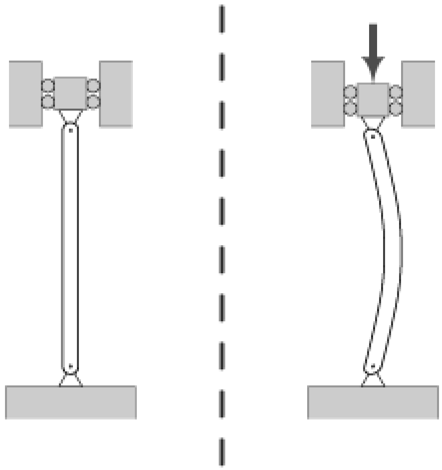

**Figure 1.1:** Strip Buckling

Source: Fae q. A.A Radwan, 2008

### 1.2.3 Critical load

For an axially loaded straight strip with any end support conditions, the equation of static equilibrium, in the form of a differential equation, can be solved for the deflected shape and critical load of the strip. With hinged or pinned, fixed or free end support conditions the deflected shape in neutral equilibrium of an initially straight strip with uniform cross section throughout its length always follows a partial or composite sinusoidal curve shape.

Elements of critical load:

E = modulus of elasticity

I = area moment of inertia

Le = strip effective length factor

### 1.2.4 Finite Element Method (FEM)

Finite Element Method **(**FEM) divides a structure into several elements or pieces of the structure.Then it is reconnecting the elements at nodes if nodes were pins or drops of glue that hold elements together.This process results in a set of simultaneous algebraic equations.The term finite element was first coined by Clough in 1960. In the early 1960s, engineers used the method for approximate solutions of problems in stress analysis, fluid flow, heat transfer, and other areas. In the late 1960s and early 1970s, the FEM was applied to a wide variety of engineering problems.

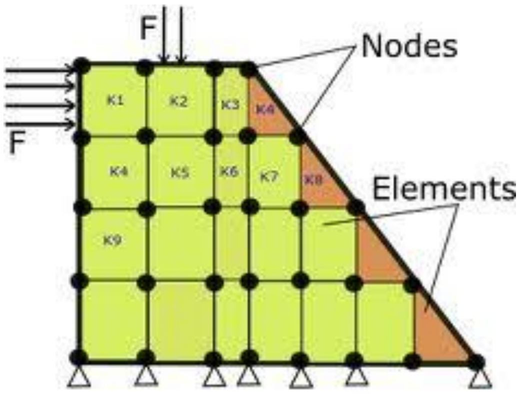


**Figure 1.2**: Finite Element Method

Source: http://www.ilearncae.com, 2010

The finite element method (FEM) which is practical application or known as finite element analysis (FEA) is a numerical technique for finding approximate solutions of partial differential equations (PDE) and also known as integral equations. The solution approach is based either on eliminating the differential equation completely steady state problems, or rendering the PDE into an approximating system of ordinary differential equations, which are then numerically integrated using standard techniques such as Euler's method, Runge-Kutta, etc. FEM are allows detailed visualization of where structures bend or twist, and indicates the distribution of stresses and displacements. FEM software provides a wide range of simulation options for controlling the complexity of modeling and analysis of a system. Similarly, the desired level of accuracy required and associated computational time requirements can be managed simultaneously to identify most engineering applications. FEM also allows entire designs to be constructed, modify, and optimized before the design is manufactured.

## 1.3 Problem Statement

Buckling phenomenon one of the natural phenomena in engineering field, thus, by this project, new design of buckling test equipment are going to be produce so that the phenomena of strip buckling can be study on more clear. The design of the test equipment should be friendly used and portably. Current teaching practices are preferring hands on or practically. Thus, it is easy and fast to understand the related engineering problem. The simple engineering problem can be investigated (by experimental) in lab and a buckling problem can be tested in lab and Finite element software can be used to develop similar model to verify the result.

## 1.4 Project Objective

The objectives of the project are to:

1. To design and fabricated new test rig for buckling test.
2. To run the experiment ofbuckling test under fixed-fixed setting.
3. Comparing result by experimental and Finite Element Software (FEM).

## 1.5 Scope of Project

In order to achieve the objectives of this project, the scopes are list as below:

1. Come out with new mechanical drawing for all part involve.
2. Come out with new complete design for buckling test equipment.
3. Fabricate the buckling test rig based on the early design (3D).
4. Run the experiment for buckling test of using sheet metal of Galvanize Mild Steel.
5. Simulate the buckling phenomenon in Abaqus software as same with experimental setup.
6. Compare the result from experimental and simulation.

## 1.6 Chapter Summary

Chapter 1 has been discussed generally about project, problems statement, objective and the scope of the project in order to achieve the objective as mention. This chapter is as a fundamental for this project and as a guidelines to complete the project research. Synopsis in this chapter is this project involve in design new model, fabricate the test rig of buckling, run the experiment and comparing the result between experimental and FEM software.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Introduction

This chapter provides the detail description literature review done according to the title of "*Experimental and Numerical Study on Sheet Metal Lateral Bending with Both Ends Fixed*". Since the aim of this project is to design and fabricate the buckling test equipment, there some are related software, methods and process. Obviously literature review related with definition of buckling phenomenon by run the experimental and simulation. This literature review will give an overview or a brief introduction of the techniques and methods that are suitable to be used in this project.

## 2.2 Buckling of Structures

A strip in structural engineering is a vertical structural element that transmits, through compression, the weight of the structure above to other structural elements below. Other compression members are often termed strip because of the similar stress conditions. Strip can be either compounded of parts or made as a single piece. Strip are frequently used to support beams or arches on which the upper parts of walls or ceilings rest. The term strip in architecture refers specifically to such a structural element that also has certain proportional and decorative features. If the load on a strip is applied through the center of gravity of its cross section, it is called an axial load. A load at any other point in the cross section is known as an eccentric load. A short strip under the action of an axial load will fail by direct compression before it buckles, but a long strip loaded in the same manner will fail by buckling (bending), the buckling effect being so large that the effect of the direct load may be neglected. The intermediate-length column will fail by a combination of direct compressive stress and bending. As the axial load on a perfectly straight slender strip with elastic material properties is increased in magnitude, this ideal strip passes through three states: stable equilibrium, neutral equilibrium, and instability. The straight strip under load is in stable equilibrium if a lateral force, applied between the two ends of the column, produces a small lateral deflection which disappears and the strip returns to its straight form when the lateral force is removed. If the strip load is gradually increased, a condition is reached in which the straight form of equilibrium becomes so-called neutral equilibrium, and a small lateral force will produce a deflection that does not disappear and the strip remains in this slightly bent form when the lateral force is removed. The load at which neutral equilibrium of a strip is reached is called the critical or buckling load. The state of instability is reached when a slight increase of the strip load causes uncontrollably. Growing lateral deflections leading to complete collapse.(Fae q A.A Radwan, 2008)

### 2.2.1 Strip buckling

Local buckling occurs in short a strip that is long enough not to fail due to crushing which mean when the compression strength of the material is not reached (Barbero, 1998). For pultruded wide-flange (WF) sections, the strip will compress axially until flanges develop wave like deformations along the length. The flange deformations can be large, often greater than the thickness of the flanges. Therefore the local buckling load can be used as failure criteria for a short strip. The short strip buckling load PL can be determined from a short strip test (Tomblin and Barbero, 1994) or predicted using analytical or numerical techniques (Banks and Rhodes, 1983).For members which are not susceptible to local buckling, there are three main different buckling modes to be considered, and they are:

(i) Flexural buckling

(ii) Torsional buckling

(iii) Flexural-torsional buckling

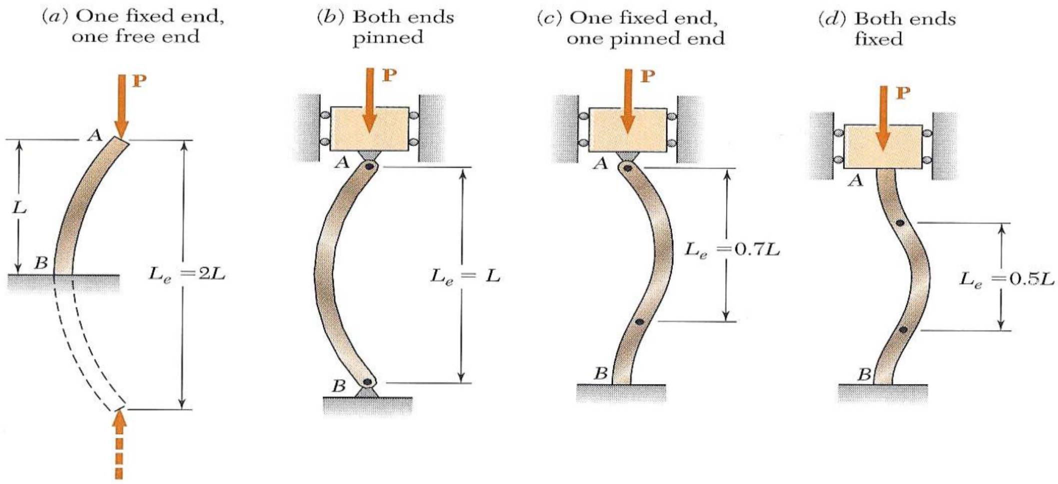


**Figure 2.1:** Cases of Strip Buckling

Sources: http://www.aplaceofsense.com, 2010

Figure 2.1 shows some cases of strip buckling cases under a uniform axial compression, the two unsupported edges tend to shape the Euler type buckles. At the fold, the amplitude of the buckle is virtually zero. A horizontal cross section at mid height of the strut shows that the cross-section rotates relative to the ends. This mode of buckling is essentially torsional in nature and is initiated by the lack of support at the free longitudinal edges. This case illustrates buckling in torsion, due to the low resistance to twisting (polar moment of inertia) of the member. Thus the strip curves of the type discussed before are only satisfactory for predicting the mean stress at collapse, when the strut buckles by bending in a plane of symmetry of the cross section, referred to as “flexural buckling”. Members with low torsional stiffness (angles, tees etc made of thin walled members) will undergo torsional buckling before flexural buckling. Cruciform sections are generally prone to torsional buckling before flexural buckling. Singly symmetric or un-symmetric cross sections may undergo combined twisting about the shear centre and a translation of the shear centre. This is known as “torsional-flexural buckling”.(Fatimah Denan et al, 2010)

## 2.3 Design

Design is an innovative and highly iterative process. It is also a decision-making process. Decisions sometimes have to be made with too little information, occasion ally with just the right amount of information, or with an excess of partially contradictory information (Richard G. Budynas and J. Keith Nisbett, 2010). Design is a communication-intensive activity in which both words and pictures are used and written and oral forms are employed. Engineers have to communicate effectively and work with people of many disciplines. Design is the human power to conceive, plan, and realize products that serve human beings in the accomplishment of any individual or collective purpose. It is a creative activity whose aim is to establish the multi-faceted qualities of objects, processes, services and their systems in whole life cycles. Therefore, design is the central factor of innovative humanization of technologies and the crucial factor of cultural and economic exchange.

### 2.3.1 Design Process

The design process is an iterative, complex, decision-making engineering activity that lead to detailed drawings by which manufacturing can economically produce a quantity of identical products that can be sold. The design process usually starts with the identification of a need, and decision to do something about it. After much iteration, the process ends with the presentation of the plans or satisfying the need. Depending on the nature of the design task, several design phases may be repeated throughout the life of the product, from inception to termination (Richard G. Budynas and J. Keith Nisbett, 2010).

## 2.4 Fabrication of Structural

The steel framed building derives most of its competitive advantage from the virtues of prefabricated components, which can be assembled speedily at site. Unlike concreting, which is usually a wet process conducted at site, steel is produced and subsequently fabricated within a controlled environment. This ensures high quality, manufacture offsite with improved precision and enhanced speed of construction at site. The efficiency of fabrication and erection in structural steelwork dictates the success of any project involving steel intensive construction. Current practices of fabrication and erection of steel structures in India are generally antiquated and inefficient. Structural steel passes through various operations during the course of its fabrication. (Ghoshal.A, 2000)

## 2.5 Euler’s Rule

In general, strip do not always terminate with simply-supported ends. Therefore, the formula for the critical buckling load had been generalized. The generalized equation takes the form of Euler's formula, mathematician Leonhard Euler derived a formula that gives the maximum axial load that a long, slender, ideal strip can carry without buckling. An ideal column is one that is perfectly straight, homogeneous and free from initial stress. The maximum load, or called the critical load, causes the strip to be in a state of unstable equilibrium, that is any increase in the load, sometimes the introduction of the slightest lateral force, will cause the strip to fail by buckling. Simple beam bending is often analyzed with the Euler-Bernoulli beam equation. The formula derived by Euler for strip with no consideration the value of critical load remains approximately same. The Euler mode occurs in slender strip and involves a sudden lateral deflection without deformation of the cross-section, as shown in equation below:

$$F = \frac{\pi^2 EI}{(Kl)^2}$$

F = maximum or critical force

E =modulus of elasticity

I =area moment of inertia

I =unsupported length of strip

K = strip effective length factor:

For both ends pinned, K = 1.0

For both end fixed, K = 0.50

For one end fixed and the other end pinned, K =1.0

For one fixed and the other end free to move laterally, K =2.0

The Euler buckling equation accurately predicts the critical buckling load for slender strip in terms of the bending stiffness *(EI)*, the strip length *L*, and the end-restraint coefficient *k*. Therefore, the Euler buckling load can be used as failure criteria for a slender strip. The reduction of buckling load due to shear deformation can be accounted for by dividing the result of Equation by *1+PE/(GA)*, where *(GA)* is the shear stiffness of the section (Gaylord and Gaylord, 1972). In addition to being a small effect, the shear stiffness *(GA)* is not reported in product literature and it is difficult to measure accurately. It is customary in steel design to predict *(GA)* as the product of the material shear modulus times the area of the web, when bending occurs about the strong axis. (Fae q A.A Radwan, 2008)]Some common boundary conditions are shown in the Figure 2.2:

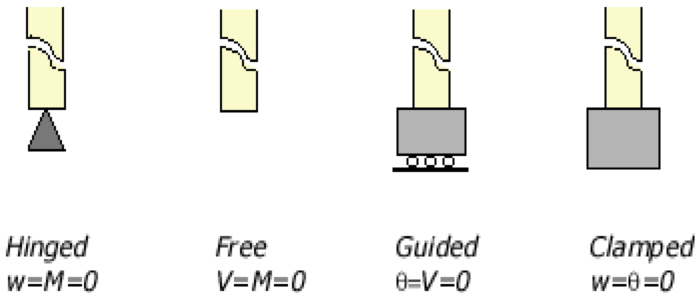


**Figure 2.2:** Boundaries condition for Buckling

Sources: http://www.aplaceofsense.com,2010

## 2.6 Strain Stress Curve

As we can see in Figure 2.3, the initial portion of the stress-strain diagram for most materials used in engineering structures is a straight line. For the initial portion of the diagram, the stress σ is directly proportional to the strain, ε. Therefore, for a specimen subjected to a uniaxial load, it is can write as equation below:

$$\sigma = E\,\varepsilon$$

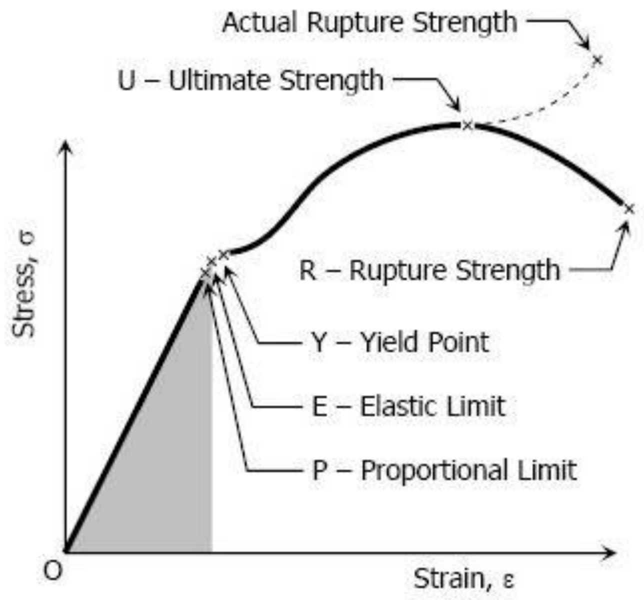


**Figure 2.3:** Strain Stress Curve

Source: http://www.keytometals.com/Article107.htm, 2009

i. Elastic Limit

The elastic limit is the limit beyond which the material will no longer go back to its original shape when the load is removed, or it is the maximum stress that may developed such that there is no permanent deformation when the load is entirely released.

ii. Elastic and Plastic Ranges

The region in stress-strain diagram from O to P is called the elastic range. The region from P to R is called the plastic range.

iii. Yield Point

Yield point is the point at which the material will have an appreciable elongation or yielding without any increase in load.

iv. Ultimate Strength

The maximum ordinate in the stress-strain diagram is the ultimate strength or tensile strength.

v. Rapture Strength

Rapture strength is the strength of the material at rupture. This is also known as the breaking strength.

## 2.7 Experimental

A wealth of experimental data is available for plates but these show no interacting stable post buckling paths (Arbocz et al, 1985, Esslinger and Geier, 1975). Guidelines for testing metallic strip are provided by Galambos in 1988 but these mostly involve interaction of a buckling mode with yield of the material. Buckling-mode interaction is investigated using conventional test procedures (Barbero and Tomblin, 1994) coupled with the shadow moiré technique (Schwarz, 1988), capable of measuring full field, out-of-plane displacements. The contributions of the local and Euler modes to the overall buckling behavior of intermediate strip is readily observed, because the two conventional buckling modes (local and Euler) as well as the emerging interactive mode are characterized by distinct and measurable physical deformations.(Ever J.Barbero et al, 1999)

## 2.8 Compression Test

The difficulties are due to the complicated boundary conditions associated with the compression loading. The difficulties are also due to the variations in the compressive strengths with the sample lengths. Unlike the uniform fixed boundary condition in the tensile experiments, it was possible for the ends of a compressed sample to move on the platen surfaces of the fixtures that were used to apply loads to the samples. It should be noted the lubricant was used in the platen surfaces of the fixture. The right angle of a triangle was used to check the alignment. The movement of sample ends on the fixture faces may result in different boundary conditions. The possible boundary conditions are ends are movable, two ends are pinned, and one end is pinned and the other end can move. The first type of boundary condition is not desirable. The data from such tests were, therefore, discarded. The latter two types of boundary conditions correspond to two types of buckling modes, and the corresponding strengths were different. Since struts in real lattice block structures are considered to be pinned at both ends, tests are considered to be valid only when there is no movement on the fixture platen for either end of the tested sample. In order to obtain the second type of boundary condition, it is important to make the top and bottom surfaces parallel. This is a necessary condition for a valid test. However, there are numerous other factors that